
WFIRST-AFTA

WFIRST-AFTA SDT

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- Neil Gehrels, NASA GSFC

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- Dave Bennett, University of Notre Dame
- James Breckinridge, California Institute of Technology
- Megan Donahue, Michigan State University
- Alan Dressler, Carnegie Institution for Science
- Scott Gaudi, Ohio State University
- Tom Greene, NASA/ARC
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- Jason Kalirai, Space Telescope Science Institute
- Jeremy Kasdin Princeton University
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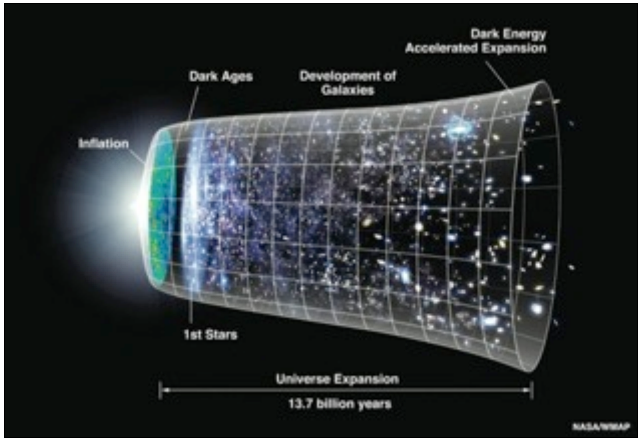
- Dominic Benford, NASA HQ
- Mike Hudson, Canadian Space Agency
- Yannick Mellier, European Space Agency
- Wes Traub, NASA/JPL
- Toru Yamada, Japan Aerospace Exploration Agency

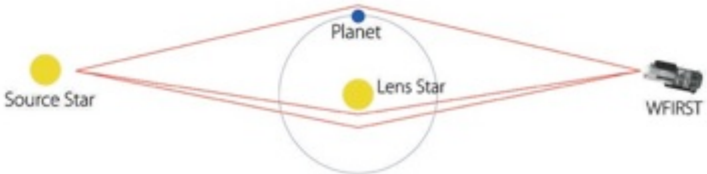
Consultants

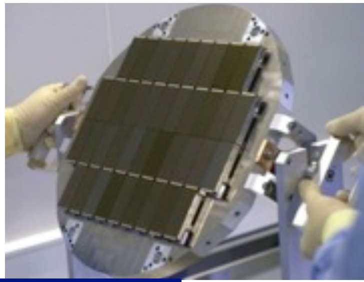
- Matthew Penny, Ohio State University
- Dmitry Savransky, Cornell University
- Daniel Stern, NASA/JPL

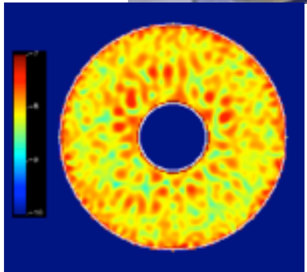
WFIRST-AFTA Summary

- WFIRST is the highest ranked NWNH large space mission.
  - Determine the nature of the dark energy that is driving the current accelerating expansion of the universe
  - Perform statistical census of planetary systems through microlensing survey
  - Survey the NIR sky
  - Provide the community with a wide field telescope for pointed wide observations
- Coronagraph characterizes planets and disks, broadens science program and brings humanity closer to imaging Earths.
- The WFIRST-AFTA Design Reference Mission has
  - 2.4 m telescope (already exists)
  - NIR instrument with 18 H4RG HgCdTe detectors
  - Baseline exoplanet coronagraph
  - 5 year lifetime, 10 year goal
- WFIRST-AFTA will perform Hubble quality and depth imaging over thousands of square degrees

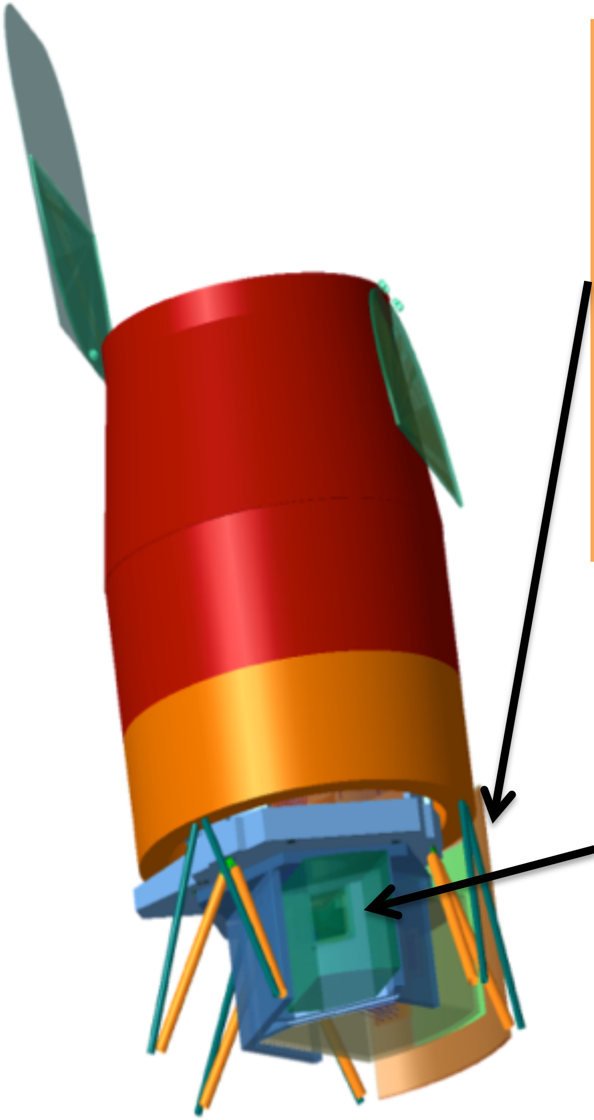








WFIRST-AFTA Instruments



Wide-Field Instrument

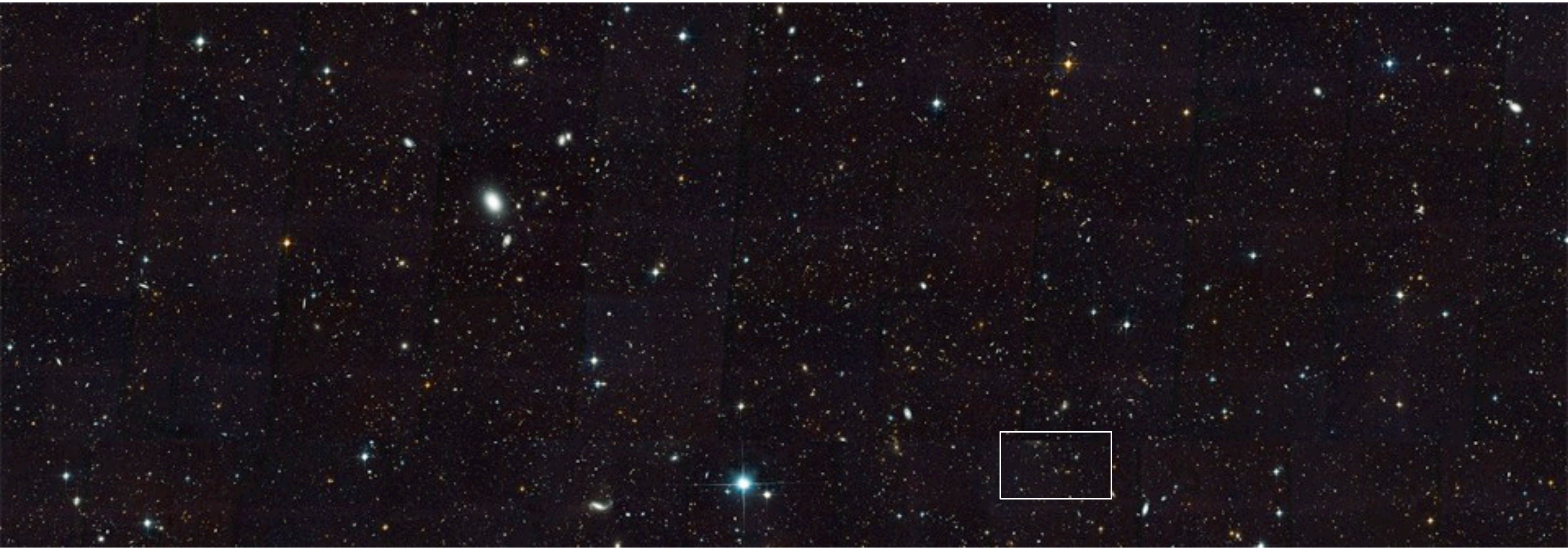
- *Imaging & spectroscopy over 1000s of sq deg.*
- *Monitoring of SN and microlensing fields*
- 0.7 – 2.0 micron bandpass
- 0.28 sq deg FoV (100x JWST FoV)
- 18 H4RG detectors (288 Mpixels)
- 4 filter imaging, grism + IFU spectroscopy

Coronagraph

- *Imaging of ice & gas giant exoplanets*
- *Imaging of debris disks*
- 400 – 1000 nm bandpass
- $\leq 10^{-9}$ contrast (after post-processing)
- 100 milliarcsec inner working angle at 400 nm

AFTA vs Hubble

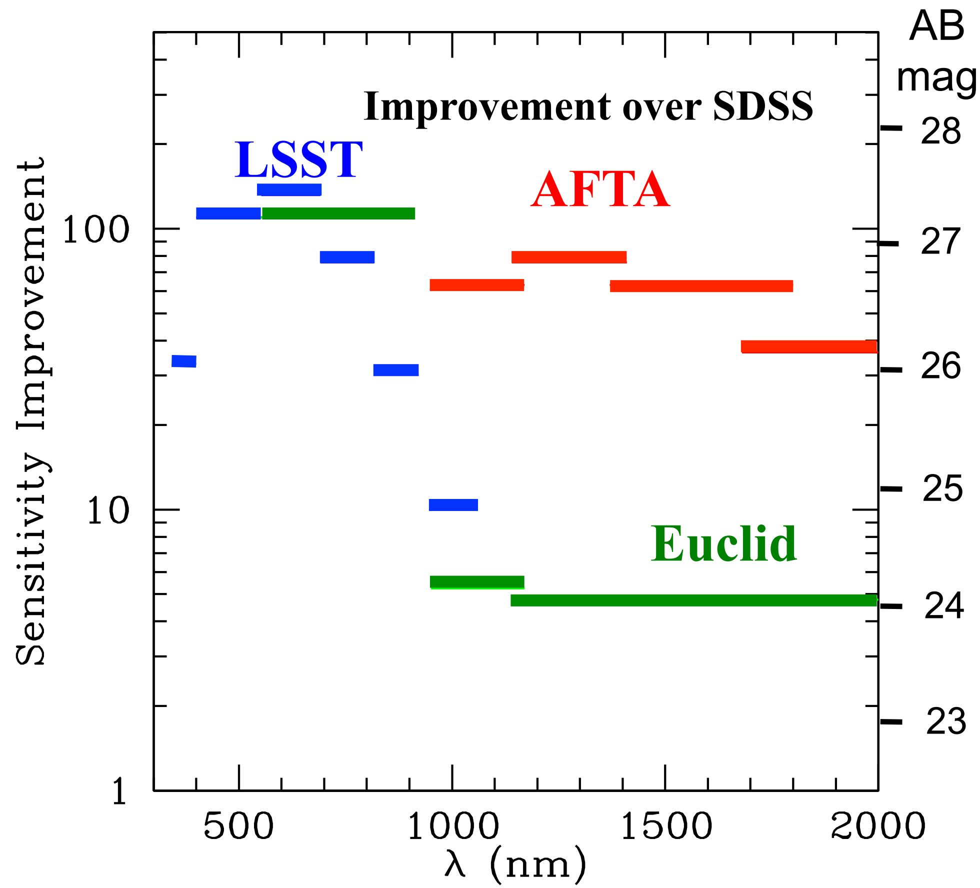
Hubble Ultra Deep Field - IR
~5,000 galaxies in one image



WFIRST-AFTA Deep Field
>1,000,000 galaxies in each image

WFIRST-AFTA Surveys

- Multiple surveys:
  - High Latitude Survey
    - Imaging, spectroscopy, supernova monitoring
  - Repeated Observations of Bulge Fields for microlensing
  - 25% Guest Observer Program
  - Coronagraph Observations
- Flexibility to choose optimal approach



High Latitude Survey is 2.5x fainter and 1.6x sharper than IDRM

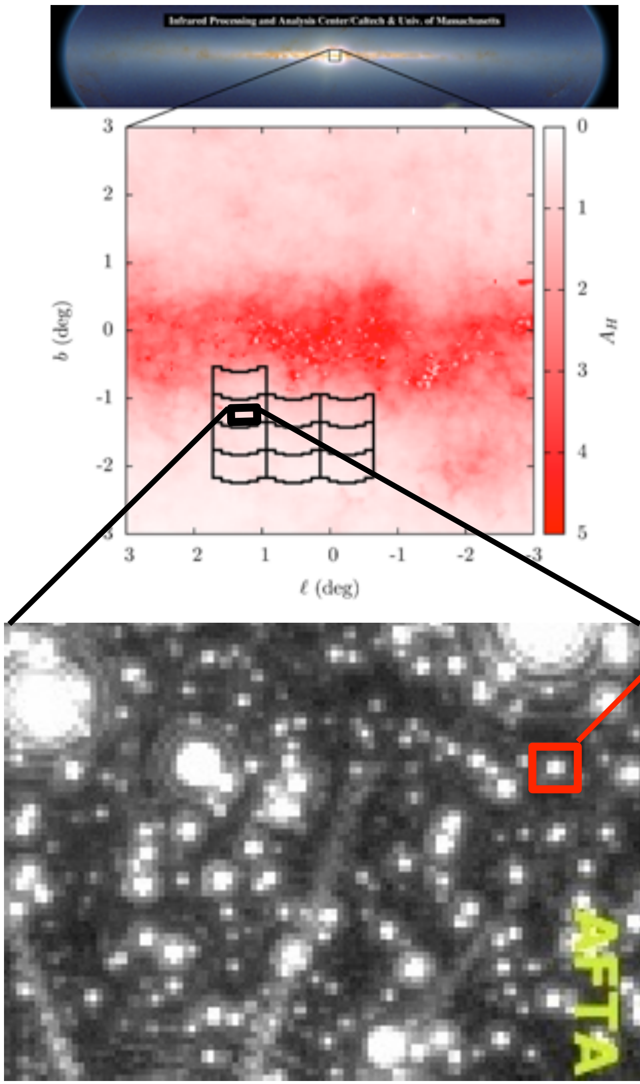
AFTA Addresses 17 of 20 Key Science Questions Ripe for Answering Identified by NWNH

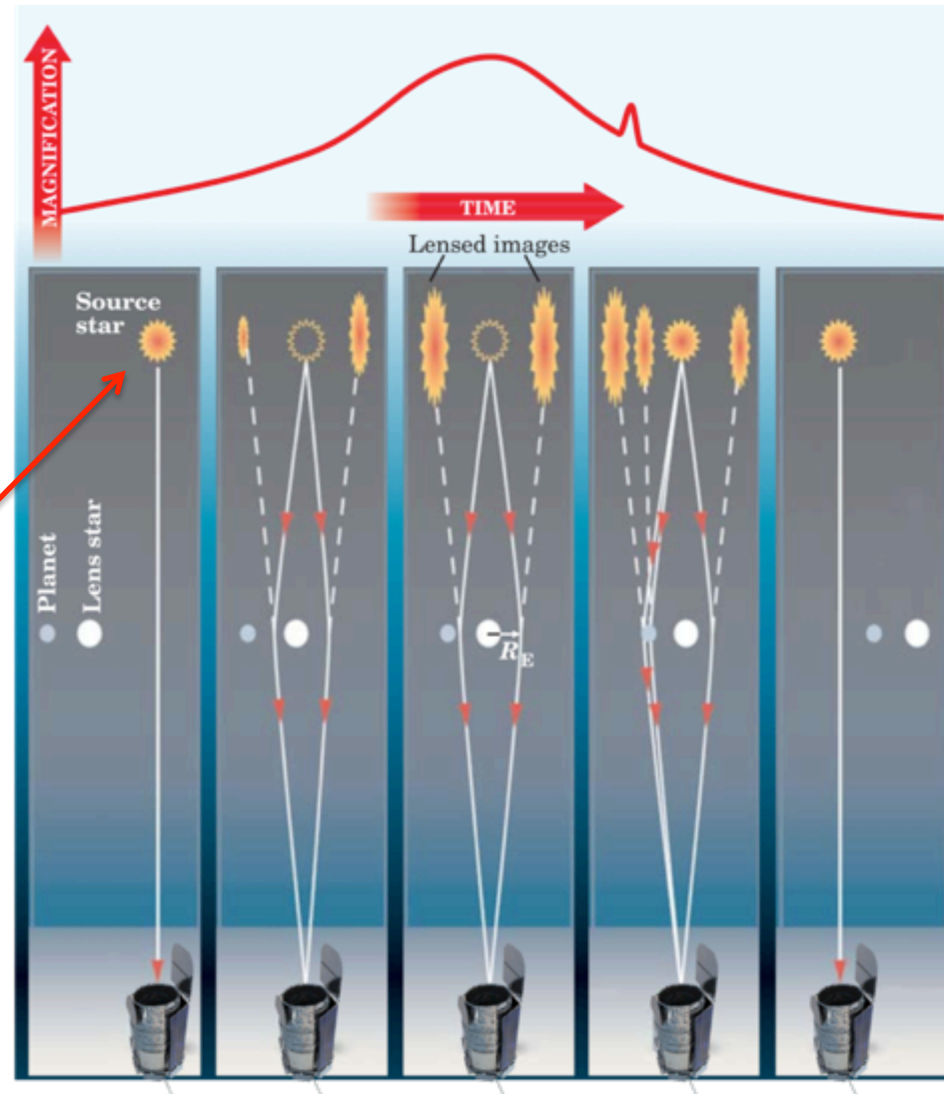
Frontiers of Knowledge	•*Why is the universe accelerating?* •*What is the dark matter?* •*What are the properties of neutrinos?* •*What controls the mass, radius and spin of compact stellar remnants?*
Understanding our Origins	•*How did the universe begin?* •*What were the first objects to light up the universe, and when did they do it?* •*How do cosmic structures form and evolve?* •*What are the connections between dark and luminous matter?* •*What is the fossil record of galaxy assembly from the first stars to the present?* •*How do stars form?* •*How do circumstellar disks evolve and form planetary systems?*
Cosmic Order: Exoplanets	•*How diverse are planetary systems?* •*Do habitable worlds exist around other stars, and can we identify the telltale signs of life on an exoplanet?*
Cosmic Order: Stars, Galaxies, Black Holes	•*What controls the mass-energy-chemical cycles within galaxies?* •*How do the lives of massive stars end?* •*What are the progenitors of Type Ia supernovae and how do they explode?* •*How do baryons cycle in and out of galaxies, and what do they do while they are there?* •*How do rotation and magnetic fields affect stars?* •*What are the flows of matter and energy in the circumgalactic medium?* •*How do black holes grow, radiate, and influence their surroundings?*

Completing the Statistical Census of Exoplanets

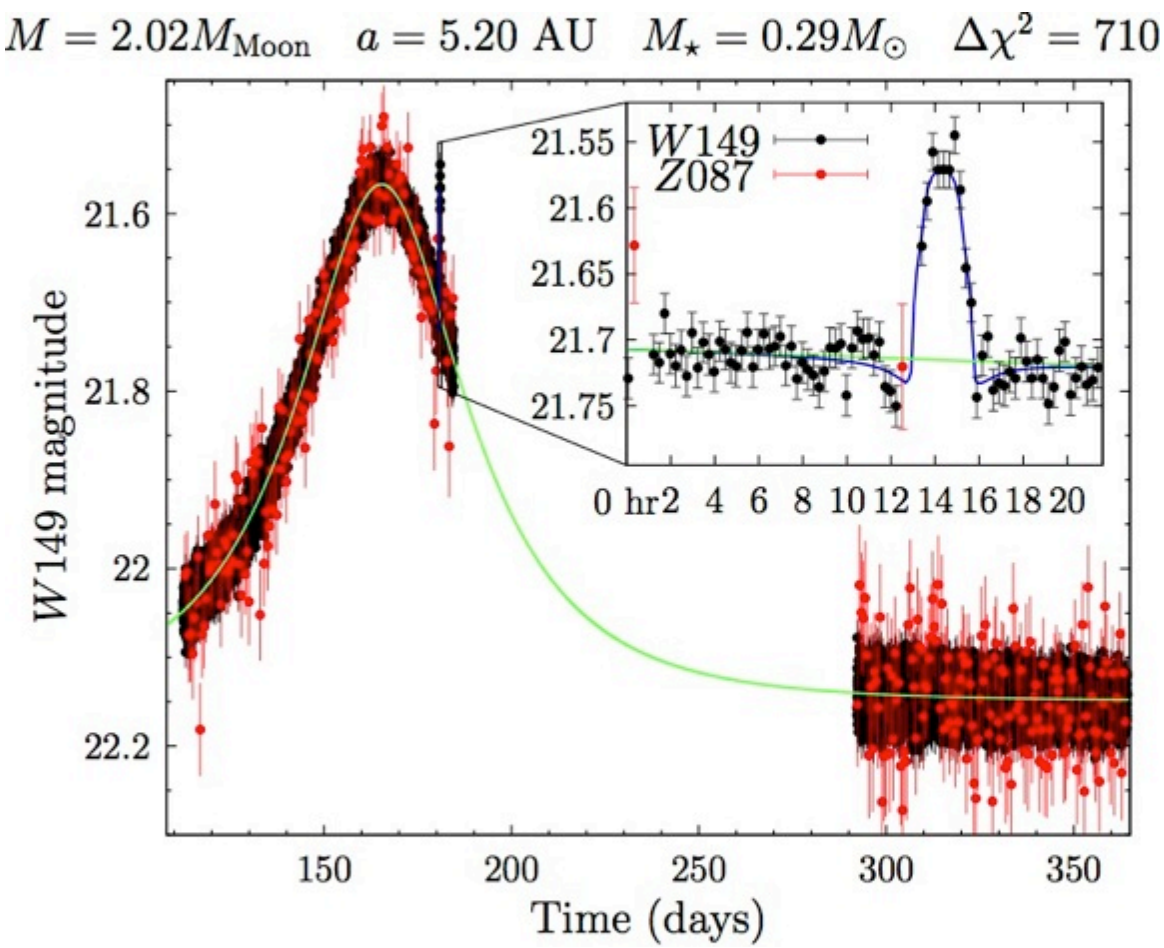
- Golden era of exoplanet science
  - Thousands of planets detected using a bewildering variety of different methods, telescopes, and instruments
  - *Kepler* has revolutionized our understanding of “hot” and “warm” planets
- But, current surveys, including *Kepler*, are mainly sensitive to planets very unlike those in our solar system
- Therefore, many questions remain:
  - How common are solar systems like our own?
  - How do planets form and migrate?
  - What kinds of planets exist in the cold, outer regions of planetary systems?
  - What determines the habitability of Earth-like worlds?
- WFIRST-AFTA will address these questions by completing the census of exoplanets begun by Kepler.
  - Detect ~3000 planets, with orbits from the habitable zone outward, and masses down to a few times the mass of the Moon
  - Sensitive to analogs of all the solar system’s planets except Mercury
  - Measure the abundance of free-floating planets in the Galaxy with masses down to the mass of Mars
  - Measure the masses and distances to the planets and host stars

Detecting Planets with a Microlensing Survey





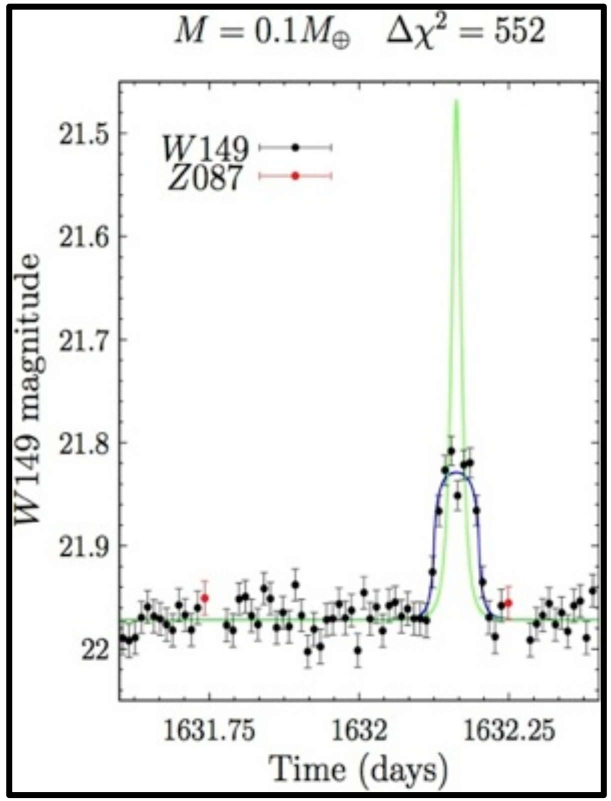
Exquisite Sensitivity to Cold, Very Low-Mass Planets



2 × Mass of the Moon @ 5.2 AU
(~27 sigma)

- Embryos with the mass of Mars or less are the building blocks of planets.
- WFIRST-AFTA can detect planets down to a few times the mass of the moon.
- Sensitive to Earth-like moons.
- Detected with high significance.

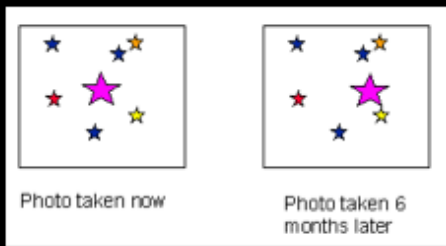
Free-Floating Planets



Free floating Mars (~23 sigma)

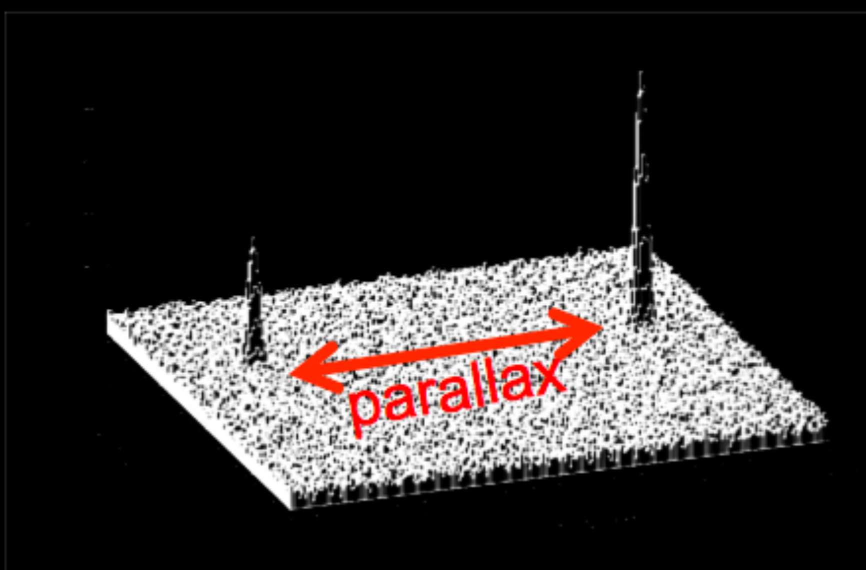
- Free-floating planets may be more common than stars in the Galaxy.
- WFIRST-AFTA can detect free-floating planets down to the mass of Mars.
- Expect to detect hundreds of free-floating planets.
- Sensitive to moons of free-floating planets.

Precision Astrometry with Spatial Scanning (PASS)

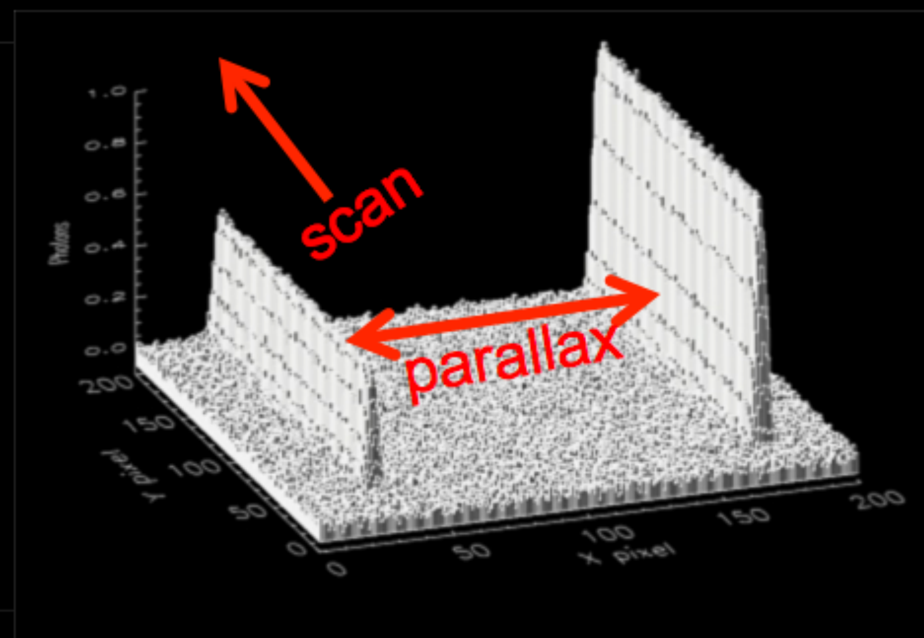


WFC3-UVIS, 0.01 pixel=400 μas~2σ @ 2 kpc

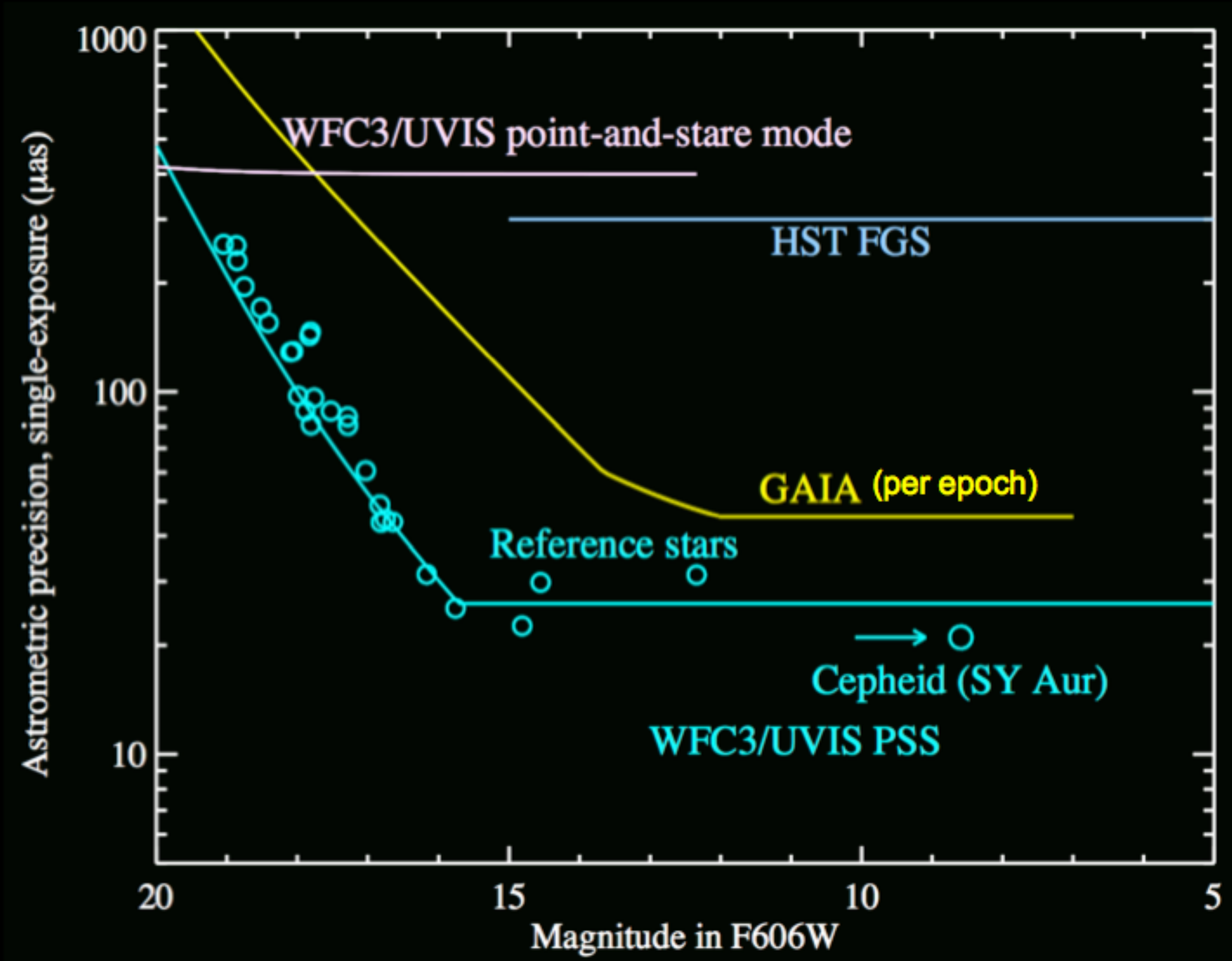
Imaging, PSF σ_θ=0.01 pix



Scanning, $\sigma_\theta=0.01/\sqrt{N\text{ samples}}$ pix



Astrometric Precision Per Exposure



Need high snr *per pixel* so bright targets give best results (350 sec scan In F606W)

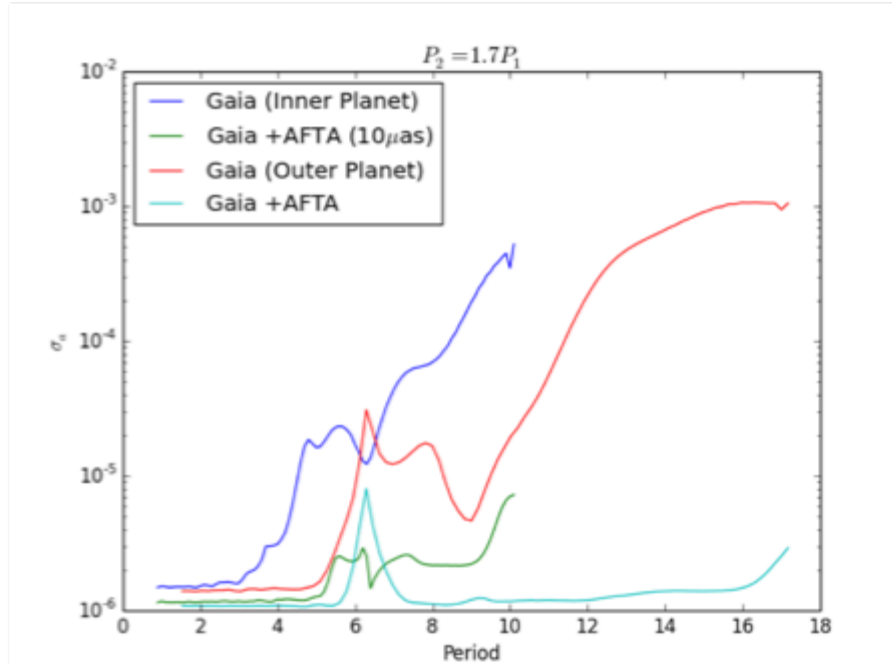
And we can measure Cepheid photometry on same system

Astrometry with AFTA

- Bigger camera should enable improved sensitivity- scales as $\sqrt{N_{pixel}}$
- At J=13.5, S/N = 400 and saturate central pixel in one second (WFC3 simulator).
- In a 3 minute integration, stars brighter than J = 19 are saturated.
- Scan at 3 degree/minute = 1600 pixels/second
- Spreads signal over 24,000 pixels
  - Assume 5x improvement over HST's 1/2000th pixel performance or 1/100th of a pixel /√24,000 (7 μas)
- Repeated 30 second integration. Achieves 10 μas astrometry for J < 10 in each integration, 25 μas for the ~30 stars with J < 14 and 100 μas for ~200 stars with J < 19
- Saturates for J = 4 at 3 deg./min, J = 3 at 10 deg/min

Nearby K and M Star Survey

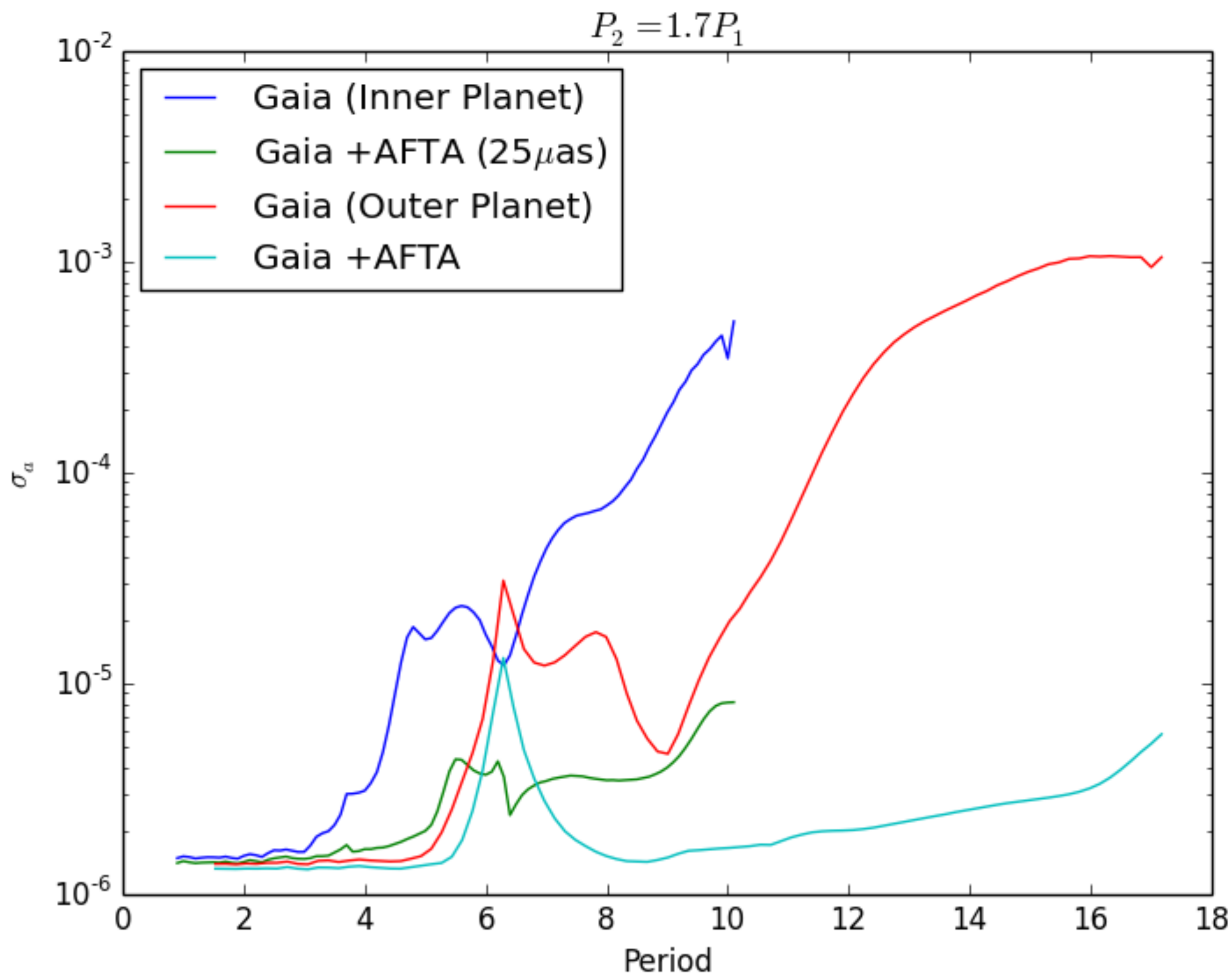
- Combine GAIA and AFTA data for $5 < V < 12$ and $J > 3$ stars.
- Make use of 15 year baseline!
- 119 stars (G8-M4.5) d< 10 pc
- Can detect Earth mass planets around nearby stars with period less than 18 yr
- 8400 obs. x 2 min= 280 hr



- Estimate sensitivity based on 70 Gaia + 70 AFTA observations and Fisher mtrix for 19 parameters (position, prop. motion, parallax and 2 planets x 7 parameters)

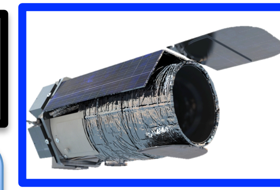
$$M_p > 3\ M_{\mathrm{Earth}} \left(\frac{d}{7\ \mathrm{pc}}\right)\left(\frac{M_*}{0.5\ M_\odot}\right)^{2/3}\left(\frac{\tau}{3\ \mathrm{yr}}\right)^{-2/3}$$

2x HST astrometry - 25 µas

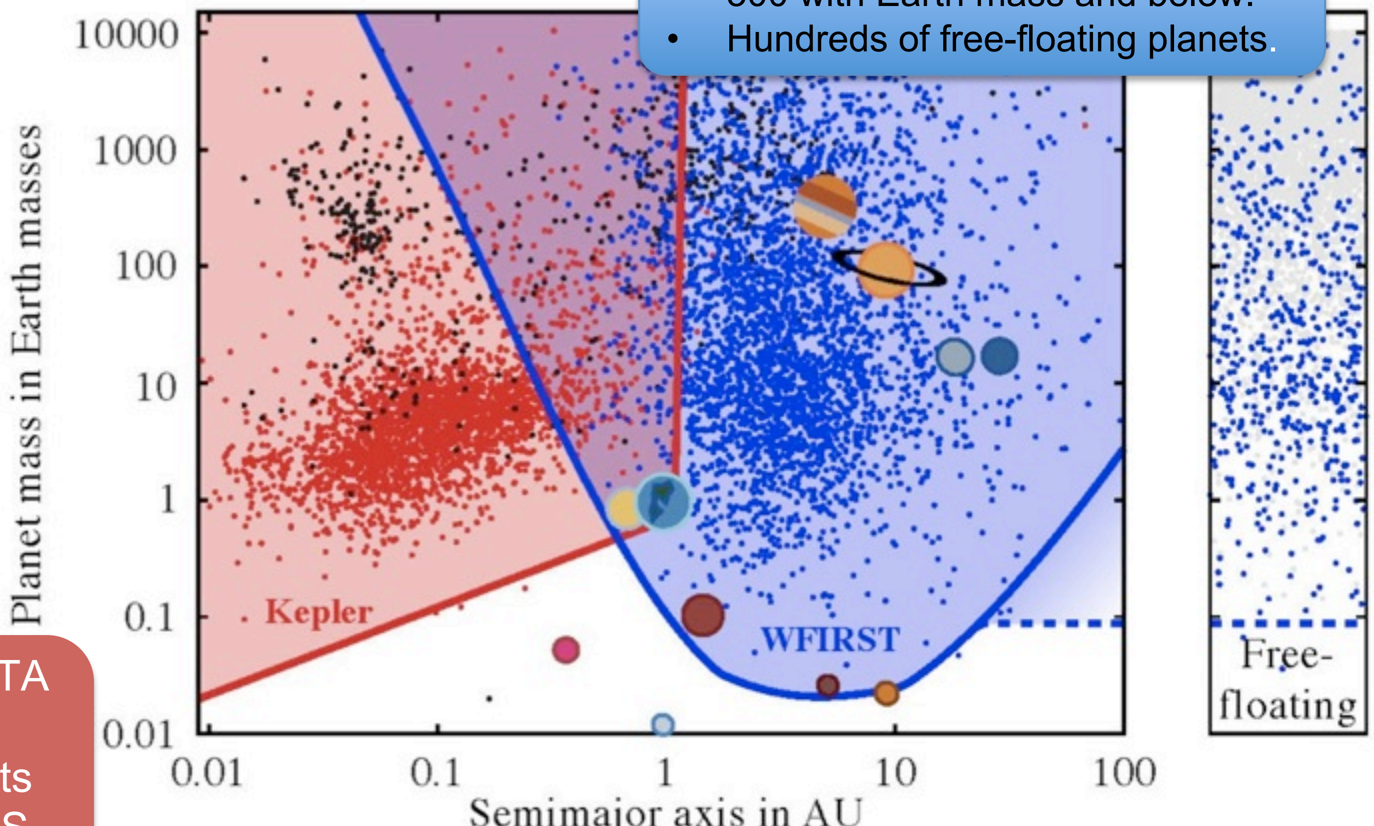


Completing the Statistical Census of Exoplanets

Combined with space-based transit surveys, WFIRST-AFTA completes the statistical census of planetary systems in the Galaxy.



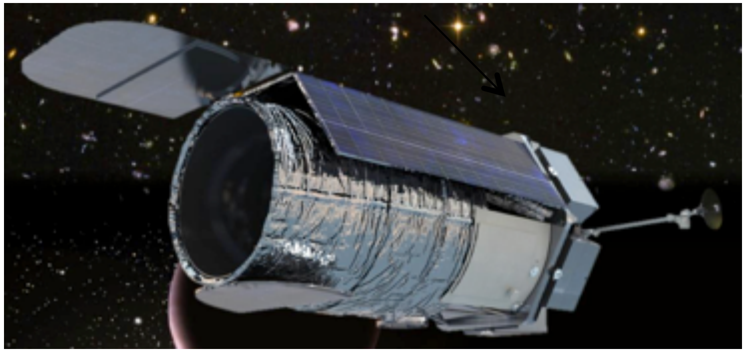
- ~3000 planet detections.
- 300 with Earth mass and below.
- Hundreds of free-floating planets.

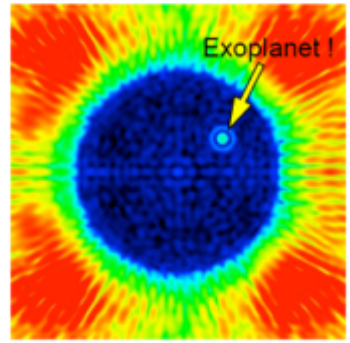


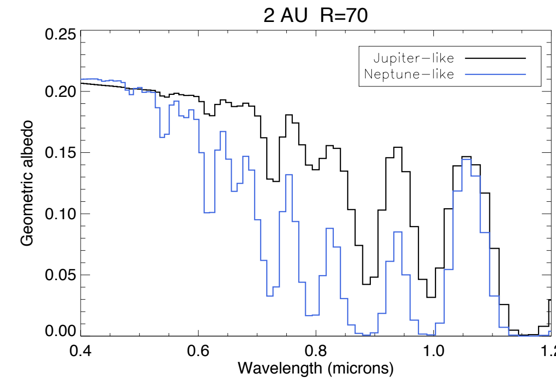
M. Penny (OSU)

WFIRST-AFTA perfectly complements Kepler, TESS, and PLATO.

WFIRST-AFTA Coronagraph Capability







Coronagraph Architecture:
Primary: Occulting Mask (OMC)
Backup: Phase Induced Amplitude Apodization (PIAA)

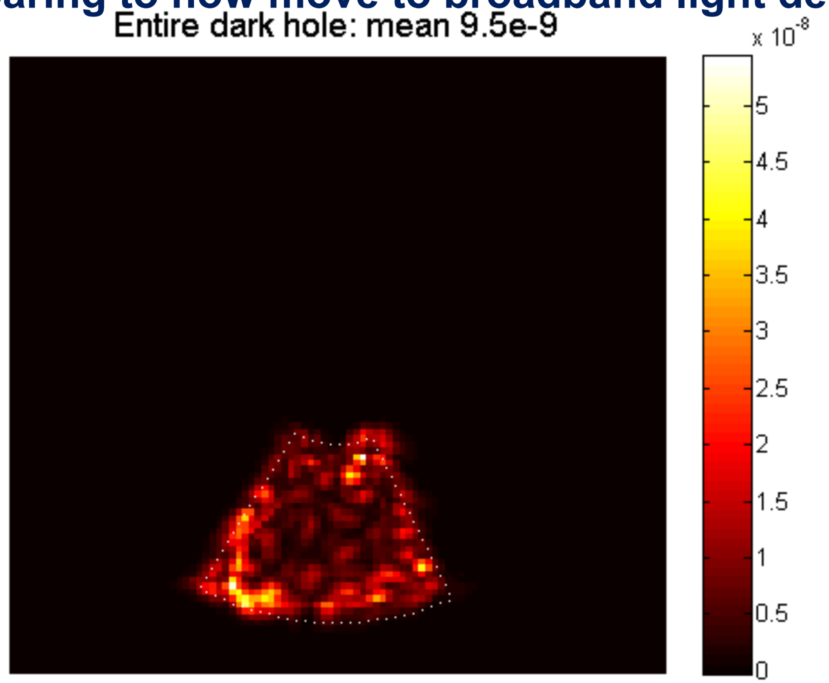
Exoplanet Direct imaging

Exoplanet Spectroscopy

Bandpass	400 – 1000 nm	Measured sequentially in five ~10% bands
Inner working angle	100 – 250 mas	~3λ/D, driven by science
Outer working angle	0.75 – 1.8 arcsec	By 48x48 DM
Detection Limit	Contrast ≤ 10^{-9} (after post processing)	Cold Jupiters, Neptunes, and icy planets down to ~2 RE
Spectral Res.	~70	With IFS, R~70 across 600 – 980 nm
Spatial Sampling	17mas	Nyquist for λ~430nm

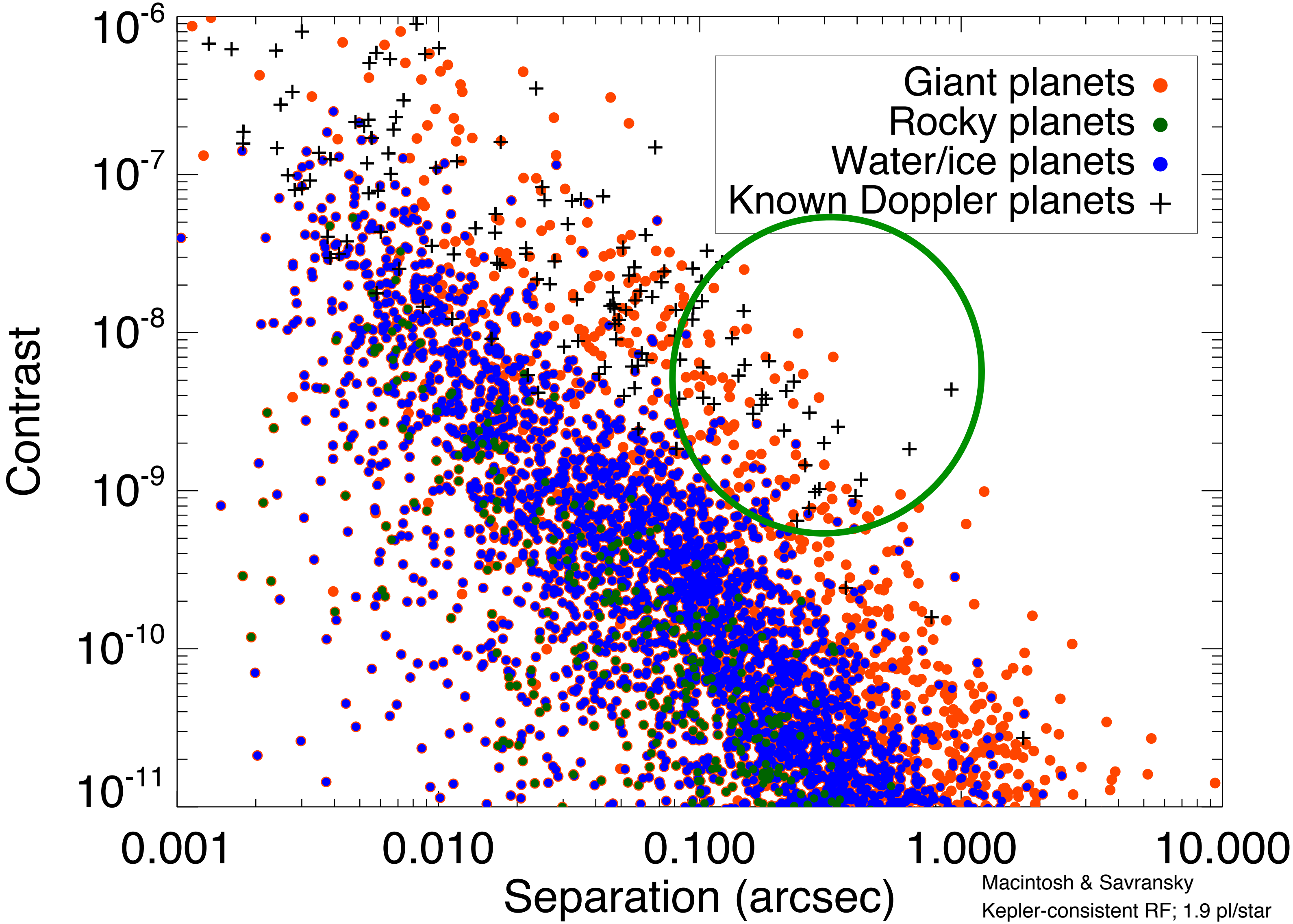
Initial Shaped-Pupil Mask Coronagraph Result

- **The AFTA coronagraph using a newly fabricated reflective Shaped-Pupil Mask met its milestone performance of < 1e-8 raw contrast ratio with monochromatic light in the High Contrast Imaging Testbed at JPL (see below) .**
  - **This mask was designed to accompany the AFTA obscured pupil**
  - **Work is continuing to push to even greater contrast and smaller inner working angles as a second deformable mirror will be added in August**
  - **The team is preparing to now move to broadband light demonstrations**



IWA: ~3.8λ/D, OWA: ~12.2λ/D

Simulated Planets within 30 pc



Macintosh & Savransky
Kepler-consistent RF; 1.9 pl/star
Main sequence non binary stars

Coronagraph Responds to NWNH Goals

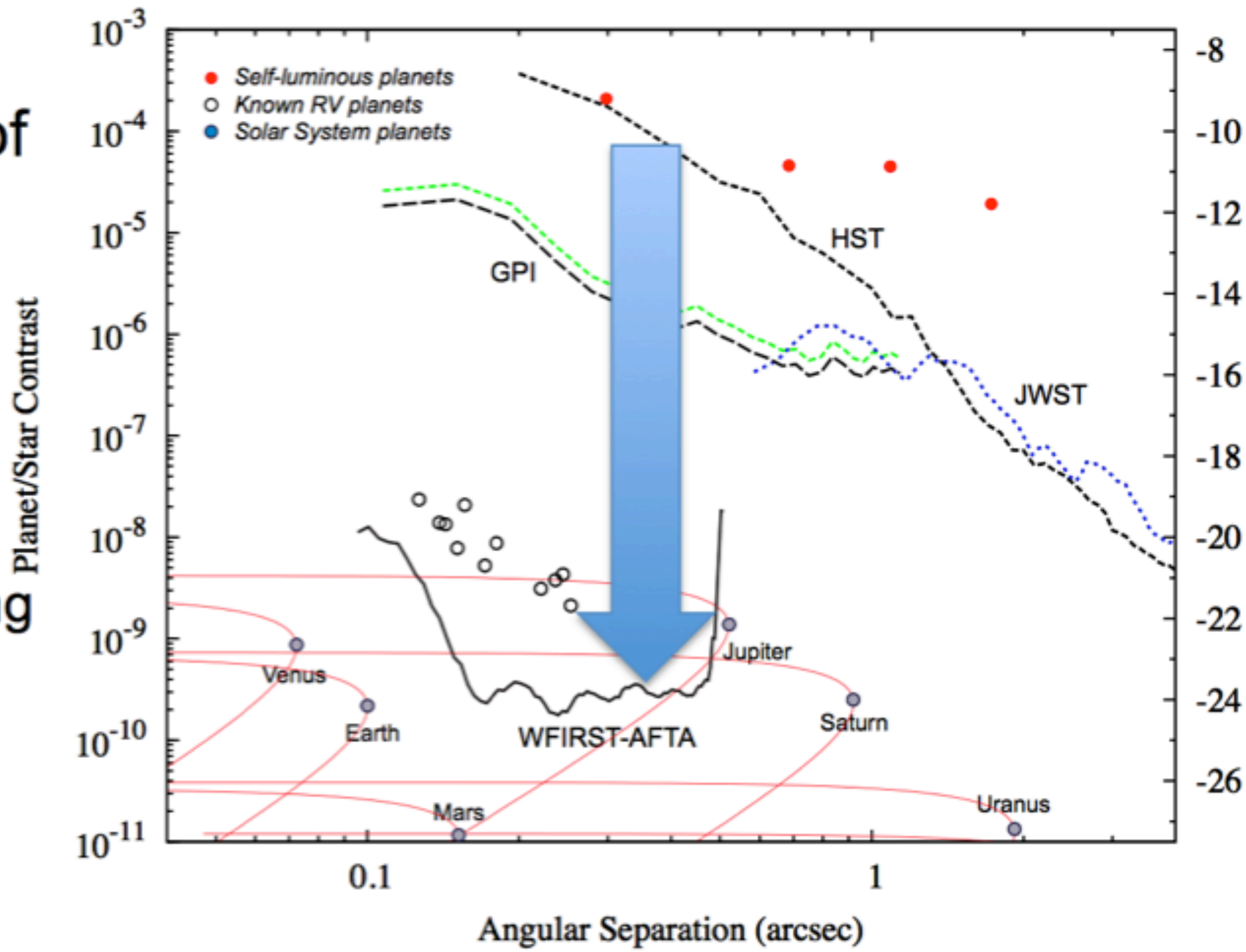
- **Observe and characterize** a dozen radial velocity planets.
- **Discover and characterize** ice and gas giants.
- Provides crucial information on the **physics of planetary atmospheres**.
- Measures the **exozodiacal disk** level about nearby stars.
- Images **circumstellar disks** for signposts of planet interactions and indications of planetary system formation.
- **Matures many critical coronagraph technologies** that will be needed for future terrestrial planet imaging mission.

While not driving requirements on observatory that could impact risk, cost, or schedule (“use as-is”).

AFTA Brings Humanity Closer to Characterizing Earths

WFIRST-AFTA advances many of the key elements needed for a coronagraph to image Earth

- ✓ Coronagraph
- ✓ Wavefront sensing & control
- ✓ Detectors
- ✓ Algorithms



NRC Review (Harrison Report)

- Concern that potential cost growth will threaten balance within astrophysics program

> **Finding 2-2: The use of inherited hardware designed for another purpose results in design complexity low thermal and mass margins, and limited descope options that add to the mission risk. These factors will make managing cost growth challenging.**

→ Investments in pre-phase A technology development and studies will **reduce these risks**
→ Will evaluate descope options in parallel with the development of the baseline design

- Highlight both rewards and risks of coronagraph program

> **Finding 2-6: Introducing a technology development program onto a flagship mission creates significant mission risks resulting from the schedule uncertainties inherent in advancing low technical readiness level (TRL) hardware to flight readiness.**

> **Finding 1-7: The WFIRST/AFTA coronagraph satisfies some aspects of the broader exoplanet technology program recommended by NWNH by developing and demonstrating advanced coronagraph starlight suppression techniques in space.**

> **Recommendation 2-1: NASA should move aggressively to mature the coronagraph design and develop a credible cost, schedule, performance, and observing program so that its impact on the WFIRST mission can be determined. Upon completion … an independent review**

WFIRST-AFTA Status

- Significant WFIRST-AFTA funding added to the NASA budget by Congress for FY13 and FY14 totaling $66M. Supported in President's FY15 budget.
- Funding is being used for pre-Phase A work to prepare for a rapid start and allow a shortened development time
  - Detector array development with H4RGs
  - Coronagraph technology development
  - Science simulations and modeling
  - Requirements flowdown development
  - Observatory design work
- NASA is currently funding community to work on relevant science mission studies! Get Involved!